THE PHENOMENON OF ANODE-SPUTTERING AND THE DEPOSITION OF METALLIC FILM ON THE CATHODE OF A HADDING'S X-RAY TUBE.

By S. SHARAN, M.Sc. (Pat.)

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ABSTRACT.—The data for the deposition of Cu and Pt films on the cathode of a Hadding's X-ray tube, during the process of its working, as published in previous papers have been put to a complete analysis with a view to explain why the rings visible on the surface of the cathode, due to the interference of light in the metallic thin film, do not all obey (a few do obey) the ordinary formula for Newton's rings formed in a medium bounded by two spherical surfaces. As a result of the analysis, it has been shown that the upper surface of the film has not got a uniform radius of curvature over the whole surface. The electrical field existing in the tube has been described and it has been shown that if the particles emitted by the anode be all of the same charge, their distribution on the cathode due to the field will be such as to produce a film of uniform radius of curvature, but if the particles be of dissimilar charges their distribution will not produce a film of uniform radius of curvature. From the analysis of the data in the present cases, it has been shown that the deposit on a limited portion near the periphery of the cathode consists of only singly charged particles, while the deposit on the rest of the cathode consists of both singly and doubly charged particles. It has been also pointed out that in the centre of the cathode, over an area of about one cm. radius there is another complication introduced due to the spluttering of the cathode by the impingement of the positive rays.

From the data a constant C can be obtained which has been shown to depend on some definite factors concerning the tube and the material of the anode. A method based on experiments of this nature has been proposed for investigating the phenomenon of anode-sputtering and an application of this to the present case gives result similar to that of the cathode-sputtering.

In the end a short discussion on the theories of anode-sputtering has been included.

INTRODUCTION

The phenomenon of cathode-sputtering and the formation of metallic films on surfaces due to particles shot out from the cathode is a phenomenon very well known and widely investigated. The allied phenomenon of anode-sputtering has been comparatively less investigated owing perhaps to the high voltage required in the process of sputtering and to a very long exposure required for the deposit of a film. About three years ago, the author[1] while working with a Hadding's X-ray tube observed brilliant coloured rings on the surface of the

concave cathode which were ascribed to the interference of light in a thin metallic film on the surface of the cathode, formed of particles shot out from the anti-cathode. The author worked with copper anti-cathode. Since then the work has been extended to platinum anti-cathode and data, obtained under the same voltage on the tube, have been published.[2] The results are similar. For example, it is observed that the curvature of the upper surface of the film is not uniform over the whole surface of the cathode, but only over a small range and hence the formula for Newton's rings holds good only for some of the rings. It is the purpose of this paper to analyse the data above referred to, in detail and to suggest reasons for the particular nature of the deposit on the surface of the cathode. Further some suggestions shall be made to utilise this sort of experiment for the investigation of the phenomenon of anode-sputtering.

GENERAL THEORY.

In the case of those rings for which the formula for Newton's rings holds good,

$$\frac{x^2}{n} = \frac{\lambda}{\mu}\,\frac{R_1.R_2}{R_1-R_2} = \text{const.} \qquad \ldots \quad (1)$$

where x – the radius of the particular rings,

R_1 and R_2 – the radii of curvature of the two surfaces of the film,

and the other terms have their usual significance.

If $R_1 - R_2$ is small, as it is in the present case,

we have,

$$\delta R = \frac{\lambda}{\mu.x^2/n}\,R^2. \qquad \ldots \quad (2)$$

In the case of rings for which x^2/n is not constant, δR is not a constant, but is a function of x and n.

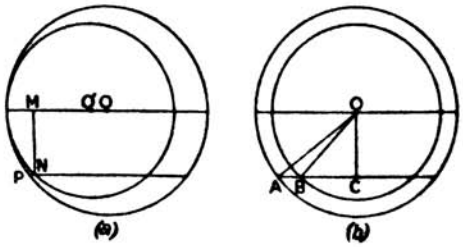

FIGURE 1.

Now we shall show how the thickness of the film may be calculated from the values of δR. Figure 1(*a*) represents the state of affairs when the cathode is deposited with the particles, the deposit at the centre of the cathode being *nil*.

Let $OO' = R_1 - R_2$ and $MN = x$

It is clear from figure 1 (*a*) that it is obtained from figure 1 (*b*) by shifting the smaller circle in such a way that its centre moves a distance OO' along a

common diameter.

$$PN = AB - OO' = AC - BC - OO'$$

$$= \sqrt{R_1^2 - x^2} - \sqrt{R_2^2 - x^2} - (R_1 - R_2)$$

Putting $R_1 = R$ & $R_2 = R - \delta R$, we get

$$t_x = PN = \delta R \left\{ \frac{R - \sqrt{R^2 - x^2}}{\sqrt{R^2 - x^2}} \right\} = \frac{\lambda}{\mu . x^2 / n} R^2 \left\{ \frac{R - \sqrt{R^2 - x^2}}{\sqrt{R^2 - x^2}} \right\} \quad \ldots (3)$$

or if $\sin \theta = \frac{x}{R}$, $t_x = \frac{\lambda}{\mu . x^2 / n} R^2 (\sec \theta - 1)$ ... (4)

The above relations have been obtained by assuming that the deposit at the centre of the cathode is *nil*. If it were not so, the terms could be corrected by the addition of a constant to t_x equal to the thickness of the film at the centre of the cathode. This is however not necessary in the present case as by visual inspection it was found that the thickness of the film at the centre of the cathode was negligibly small.

A few remarks about the field existing in the Hadding's tube and the trajectory of the particles shot out from the anti-cathode will be made here.

In Hadding's tube the anode and the metallic cylindrical wall of the tube are at the same potential, while the cathode is maintained at a high negative potential with respect to the anode. Usually the anode is situated at the centre of curvature of the cathode. In such a state of affairs the field at a point inside the tube will be the resultant of two fields :—

(1) along the radius of curvature of the cathode passing through the point,

(2) along the radius of the cylindrical tube passing through that point. This field goes on increasing as the point approaches the cathode.

The resultant field at a point can be resolved in two mutually perpendicular directions, along the axis and the radius of the cylindrical tube. These two components of the field will vary in magnitude from point to point and a particle in its path gains acceleration in these two directions whose magnitude varies from point to point.

Let us now assume that the particles are shot out from the anode in all possible directions with an initial speed which is the same for all the particles. This is quite reasonable and follows from any theory of sputtering discussed in the end of this article. The trajectory of the particle shot out in a direction making an angle α to the axis of the tube may now be considered.

It is clear that because of the complex nature of the field in the tube, the trajectory of the particle will not be a simple one. For the sake of simplicity, let us first of all postpone considering the effect of the axial field. Due to the radial component the particles will experience an acceleration along the radius of the cylindrical tube and directed towards the axis of the tube. This acceleration

is varying from point to point in magnitude but we can conveniently replace this acceleration by a constant acceleration which, though it does not produce the exact trajectory of the particle as before, lands a particle on the cathode at the same point as the varying acceleration. Under these conditions the trajectory is similar to that of a projectile in the earth's field of gravitation. Thus we have,

$$\left.\begin{aligned} x &= R\tan\alpha - \tfrac{1}{2}g\frac{R^2}{u^2\cos^2\alpha} \\ &= R\tan\alpha\left(1-\frac{R}{a}\right) \end{aligned}\right\} \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

where

x—the distance of the point where the particle lands from the centre of the cathode.

R—the distance between the cathode and the anode,

u and α—initial velocity and direction of projection, and

a—the range of the particle

$$= \frac{u^2\sin 2\alpha}{g} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (6)$$

From (5),

$$\frac{dx}{d\alpha} = \frac{R}{\cos^2\alpha} - g\frac{R^2}{u^2}\frac{\tan\alpha}{\cos^2\alpha} \quad \ldots \quad \ldots \quad (7)$$

The second term increases at a more rapid rate than the first term and hence $\frac{dx}{d\alpha}$ goes on decreasing with increase of α. Now assuming the number of particles shot out in all directions to be the same, this means that near the centre of the cathode there will be a small number of particles per unit area and this number goes on increasing from the centre to the periphery of the cathode. The thickness of the film will therefore increase from the centre outwards and hence a change δR will be introduced in the previous radius of curvature of the cathode. If the number shot out in different directions be not the same,* the value of δR will be simply modified depending on the function of distribution.

The effect of the axial field which we have postponed so far, may now be considered. It is clear that the effect of this field will be to increase the axial velocity of the particle and this results merely in decreasing the radius of curvature of the trajectory. The change δR in the radius of curvature of the cathode is therefore smaller than that in the absence of the field.

So far, we have considered the particles which have all equal charges. In fact there must be singly, doubly or multiplely charged particles in the tube. The effect of this will be taken up under 'the discussion of results.'

* In the case of cathode-sputtering it has been shown by Seeliger and Sommermeyer [8] that the number of particles shot out in different directions follows the Knudsen's cosine law of distribution.

RESULTS.

Pt film. (*Ring system viewed with Na yellow*).

$\lambda = 5893 \times 10^{-8}$ cms.; $\mu = 2{\cdot}01$ (International Critical Tables); R = 6·8 cms.

TABLE I.

1	2	3	4	5	6	7	8	9	10	11	12
Serial number of dark ring.	x cms.	x^2	n Interference order	$\frac{x^2}{n}$	δR cms.	Sec $\theta - 1$	t, microns	$x^2_n - x^2_{n-1}$	n' Integer nearest to the ratio of x^2 and mean $x^2_n - x^2_{n-1}$	$\frac{x^2}{n'}$	K $= \delta R . \frac{n'}{n}$
1	1·5400	2·3716	2	1·1858	·001143	·02664	·3046		(9·08) 9	·2635	·005143
2	1·6200	2·6244	3	·8748	·001550	·02965	·4594	·2528	(10·05) 10	·2624	·005167
3	1·6300	2·8561	4	·7140	·001899	·03243	·6157	·2317	(10·94) 11	·2596	·005222
4	1·7850	3·1859	5	·6372	·002127	·03635	·7732	·3298	(12·20) 12	·2655	·005105
5	1·8500	3·4225	6	·5704	·002327	·03917	·9311	·2366	(13·11) 13	·2633	·005150
6	1·9175	3·6773	7	·5253	·002580	·04234	1·0926	·2548	(14·08) 14 and (6·98) 7	·2626 and ·5253	·005160 and ·002580
7	2·0500	4·2025	8	·5253	·002580	·04876	1·2585	·5252	(7·98) 8	·5253	·002580
8	2·1750	4·7304	9	·5256	·002580	·05544	1·4302	·5279	(8·98) 9	·5253	·002580

Mean = ·2611

Mean = ·5265

Pt film—*contd.* (*Ring system viewed with Hg green*).

$\lambda = 5461 \times 10^{-8}$ cms ; $\mu = 1{\cdot}85$ (International Critical Tables) ; R = 6·8 cms.

TABLE 2.

1	2	3	4	5	6	7	8	9	10	11	12
Serial number of dark ring	x cms	x^2	n Interference order	$\frac{x^2}{n}$	δR cms	Sec $\theta - 1$	t, microns	$x^2_n - x^2_{n-1}$	n' Integer nearest to the ratio of x^2 and $x^2_n - x^2_{n-1}$ (mean)	$\frac{x^2}{n'}$	$K \frac{n'}{n} = \delta R$.
1	1·5575	2·4257	2	1·2133	·001126	·02738	·3071		(8·93) 9	·2695	·005067
2	1·6475	2·7143	3	·9048	·001509	·03071	·4633	·2886	(10) 10	·2714	·005030
3	1·7050	2·9075	4	·7268	·001878	·03299	·6196	·1932	(10·71) 11	·2643	·005165
4	1·8200	3·3124	5	·6625	·002061	·03787	·7802	·4049	(11·98) 12	·2760	·004946
5	1·8800	3·5344	6	·5890	·002317	·04057	·9401	·2220	(13·02) 13	·2719	·005020
6	1·9450	3·7831	7	·5405	·002526	·04362	1·1014	·2487	(13·93) 14 & (7·08) 7	·2702 & ·5405	·005052 & ·002526
7	2·0750	4·3054	8	·5383	·002536	·05009	1·2703	·5223	(8·06) 8	·5383	·002536
8	2·2025	4·8513	9	·5390	·002533	·05702	1·4439	·5459	(9·08) 9	·5390	·002533

mean— ·2715

mean— ·5341

Cu film. (*Ring system viewed with Na yellow.*)

$\lambda = 5893 \times 10^{-8}$ cms ; $\mu = \cdot 64$ (Landolt & Bornstein Tabellen) ; R = 7·6 cms.

TABLE 3.

1	2	3	4	5	6	7	8	9	10	11	12
Serial number of dark rings	x cms	x^2	n Interference order	$\frac{x^2}{n}$	δR cms.	Sec $\theta - 1$	t, microns	$x^2_{n'} - x^2_{n'-1}$	Integer nearest to the ratio of x^2 and mean $x^2_{n'} - x^2_{n'-1}$ n'	$\frac{x^2}{n'}$	$K \frac{n'}{n} = \delta R$
1	·5680	·3226	3	·1076	·04943	·002783	1·3756		(·595) 1 x	—	·009804
2	·9385	·8808	4	·2205	·02412	·007689	1·8546	·5582 } mean — ·5418	(1·62) 2 x	—	·009768
3	1·1860	1·4062	5	·2866	·01856	·01243	2·3066	·5254 }	(2·59) 3 x	—	·009712
4	1·3485	1·8186	6	·3030	·01754	·01614	2·8330	·4124	(6·2) 6	·3030	·01754
5	1·4385	2·0695	7	·2998	·01773	·01847	3·2767	·2509	(7·05) 7	·2998	·01773
6	1·5480	2·3964	8	·2995	·01775	·02145	3·8078	·3269 mean — ·2933	(8·17) 8	·2995	·01775
7	1·6370	2·6800	9	·2978	·01786	·02404	4·2931	·2836	(9·13) 9	·2978	·01786
8	1·7300	2·9929	10	·2993	·01777	·02693	4·7841	·3129	— { (10·20) 10 & (6·19) 6	{ ·2993 & ·4988	{ ·01777 & ·01066
9	1·8645	3·4762	11	·3160	·01683	·03156	5·3116	·4833	(7·19) 7	·4966	·01071

EXPLANATIONS OF THE TABLES.

The first five columns have been taken from the papers referred to. The sixth column contains δR as calculated from relation (2). The seventh column contains sec $\theta - 1$, calculated from relations (3) and (4). t_x is then obtained by multiplying δR and sec $\theta - 1$. Figure 2 shows the variation of t_x with x and figure 3 shows the variation of t_x with sec $\theta - 1$.

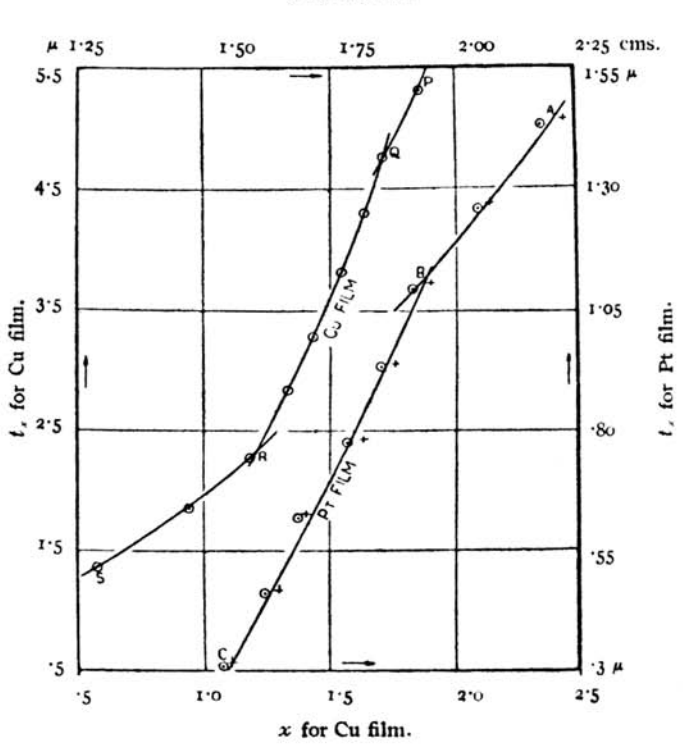

FIGURE 2.

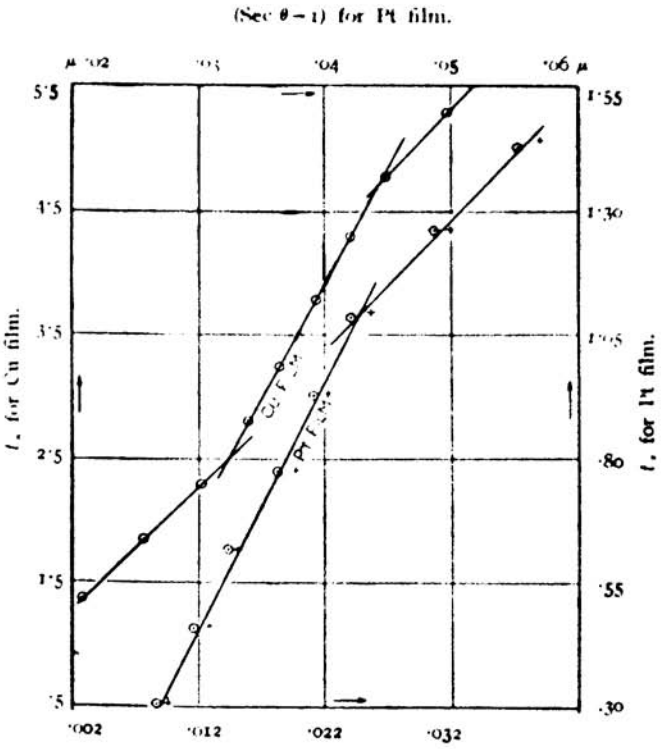

FIGURE 3.

It is seen that the whole region of the cathode is divided into three different portions in the case of the copper film and two in the case of the platinum film. From figure 3 it is seen that the variation of t_x with sec $\theta - 1$ is linear in every portion of the curve. In those portions where δR is constant it is this constant value which is the constant of proportionality, as should naturally follow from relation (4). Where δR is not constant but is a function of x and n, the variation of t_x with sec $\theta - 1$ is still a linear one and the constant of proportionality is $\delta R \frac{n'}{n}$ where n' is an integer calculated and explained in 9th and 10th columns of the tables. In general for every portion of the curve we can write the constant of proportionality $K = \delta R \frac{n'}{n}$ where n' may be either same as n or different from it. From equation (2) we get,

$$K = \frac{\lambda}{\mu x^{\theta/n'}} R^{\theta} \quad \ldots \quad \ldots \quad (8)$$

where n' may be the same as n or different from it. Now as $\frac{x^2}{n'}$ is a constant for any portion of the curve, we can write

$$K = CR^2 \quad \ldots \quad \ldots \quad \ldots \quad (9)$$

where $$C = \frac{\lambda}{\mu \sqrt{x^2/n'}} \quad \ldots \quad \ldots \quad \ldots \quad (10)$$

and is the same for any portion of the curve but differs from portion to portion.

The cross mark in the 10th column (table 3) indicates that the integers are very far from the ratios which are shown in the brackets. Hence in calculating the values in the last column the actual ratios in the brackets and not the integers have been taken to represent n' in these cases.

DISCUSSION OF THE RESULTS.

Let us first of all investigate the reasons for the variation of δR over the surface of the cathode.

It has been suggested [2] that the inconstancy in the value of $\frac{x^2}{n}$ and hence of δR may be due to abnormal values of μ when the film is thin. According to this suggestion the results show that μ should be different for the different portions of the curve, but same for same portion and that the variation of C from portion to portion is really the variation of μ for the different portions. This suggestion though qualitatively plausible, fails when quantitative tests are applied. Pogany[4] has shown that when the thickness of a Pt film falls below $15m\mu$, it shows abnormal refractive index. Above this value the refractive index is normal. Examining the values of t_x for Pt film it will be seen that the thickness of the film is many times this value even in the place where the first ring is situated. Thus we see that the suggestion is not tenable here.

We suggest that the change in K from one portion to another is due to the presence of multiplely charged particles in the tube. If there were only singly charged particles in the tube they would be distributed on the surface of the cathode in such a way as to produce a constant δR, as explained in the beginning of the paper. But if on any portion of the cathode the deposit consists of two kinds of particles, *i. e.*, singly and doubly charged ones, δR is a resultant effect due to the distribution of the two kinds of particles and differs from place to place. The resultant C however is the algebraic sum of the C's for the two types of particles.

Thus $$C_{M^+, M^{++}} = C_{M^+} + C_{M^{++}} \quad \ldots \quad \ldots \quad \ldots \quad (11)$$

where $C_{M', M}$ denotes the constant C for the region where the deposit consists of both singly and doubly charged particles and M represents the metal whose film is deposited on the cathode.

According to the above suggestion the portion AB of the curve for the Pt film refers to the deposit of only singly charged particles and BC to the deposit of both singly and doubly charged particles. Similarly in the case of the copper film the portion PQ refers to the deposit of only singly charged particles while QR refers to the deposit of both singly and doubly charged particles. It is clear that the doubly charged particles being repelled by the walls of the tube will be confined to space near about the centre of the cathode, and will not spread on the whole of the cathode. The points B and Q refer to the position where a doubly charged particle shot out in the most extreme direction is brought to land on the cathode.

Let us now compare the distances of B and Q from the centre of the cathode. Before doing so we must investigate how the distance x of a point, where a particle shot out in a direction α lands on the cathode, varies with the distance R between the anode and the cathode. This is necessary because this distance R is not the same in both the cases.

From relation (5), we have,

$$x = R \tan \alpha \left(1 - \frac{R}{a}\right) \text{ or } \frac{dx}{dR} = \tan \alpha \left(1 - \frac{2R}{a}\right)$$

and is negative if $R > \frac{a}{2}$.

As the exact shape of the trajectory is very complex it is difficult to say, how x will vary with R. In the case of parabolic trajectory we can write for small changes of R,

$$x \propto \frac{1}{R} \quad \ldots \quad \ldots \quad \ldots \quad (12)$$

This approximate relation is verified if we compare the distances of points B and Q from the centre of the cathode.

Thus $\frac{x_B}{x_Q} = \frac{1{\cdot}94}{1{\cdot}74} = 1{\cdot}115$

and $\frac{R_{Cu}}{R_{Pt}} = \frac{7{\cdot}6}{6{\cdot}8} = 1{\cdot}118$

We have said that in the case of the copper film the portion PQ refers to the deposit of singly charged particles alone whereas the portion QR refers to the deposit of both singly and doubly charged particles. It might be argued against this statement that δR is not constant over PQ whereas it is constant

over QR and hence QR should refer to a region where there is deposit of only one sort of particle whereas PQ to the deposit of more than one kind of particle. Against this argument we have to point out that δR in the sixth column has been calculated from n, the interference order which was selected arbitrarily to show as many rings as possible obeying the Newton's formula. There is however no other justification for this selection. If instead of these values, we ascribe the interference order 7 to the last ring, 6 to the last but one, and so on, $\frac{\lambda^2}{n}$ will be constant only for the last two rings and will differ for all the other rings and then δR will be constant over the region PQ but will vary over QR. The facts that these numbers are smaller than those selected previously and that the selection of these numbers makes the case of copper film similar to that of the Pt film and hence capable of being explained by the same theory, suggests that these numbers are probably the true interference orders.

According to this, the changes introduced in the table 3 will be the following :—

(1) In the fourth, fifth, and the sixth columns changes will have to be made according to the new values of the interference order.

(2) The values of t_2 will be decreased in the same proportion as the change in the value of the interference order.

The values of n and other columns in the table will remain the same and hence the values of C will not change.

We have not up till now considered the portion RS of the curve for the copper film. It will be noted that this portion of the curve shows many anomalous characteristics.

We notice in the very beginning that the constant C for this portion of the curve is smaller than that for QR. Hence we cannot ascribe this to be due to any fresh deposit of some differently charged particles over and above those of the singly and the doubly charged ones. We also notice that the ratio of x^0 and $x_n - x_{n-1}$ for the rings in this region is far removed from any integer. Moreover if we ascribe smaller integers for the interference order (7 for the last ring, 6 for the last but one, and so on) as suggested a little previously, we find that the third ring gets the order 1 and it is difficult to ascribe any order to the 1st or 2nd ring on the same system. Thus it seems that these rings in the region RS do not belong to the same system as the other rings and this suggests that in this region not only the upper surface has got a varying radius of curvature but also the original surface of the cathode has somehow come to possess a different or irregular radius of curvature.

Another fact about this region which has not been mentioned in any of the papers referred to, but had been observed by the author while he worked with the

copper anti-cathode may be stated here. It was observed that the central portion of the cathode, an area of about one cm. radius presented a spluttered appearance. Of course, there was some deposit of a thin film over and above the spluttered portion.

We suggest that the anomalous nature of the curve RS is due to the spluttering of the cathode in this region, due to the impingement of positive rays on it. It is known that the positive rays consisting of charged particles of light atoms are more effective in causing spluttering than particles of heavy atoms, so much so that the particles of mercury do not cause any spluttering at all.[5] As the positive rays consisting of light atoms are confined to a small portion near the axis of the tube, spluttering is observed only on a small portion near the centre of the cathode.

Again, the particles forming the positive rays are influenced by the electric field in the tube, in the same way as the other particles sputtered out from the anode. Hence they are less numerous on the axis than on the periphery of the region. This will cause a greater spluttering of the cathode on the peripherial portion of the region than on the portion near the centre of the cathode, and hence due to mere spluttering an increase in the radius of curvature will take place. Over and above this is the decrease in the radius of curvature due to deposit of particles and hence we observe that the constant K for this portion of the curve is smaller than that for the portion QR.

So far, a satisfactory explanation of the phenomenon has been given. Next the factors on which the constant C depends will be analysed.

From the nature of the problem the factors on which the constant C depends are the following :—

(1) N—the number of particles emitted in unit time by the anode per unit area of an imaginary sphere of unit radius drawn about the anode. (Dimensions—L_*^{-2}. T^{-1}.)

(2) $\frac{e}{m}$ of the particles. (Dimensions—$M^{-\frac{1}{2}}$. $L_*^{3/2}$. T^{-1}.)

(3) F—the electrical field in the tube. (Dimensions—$M^{\frac{1}{2}}$. $L_*^{-\frac{1}{2}}$. T^{-1}.)

(4) t—the time for which the tube is run. (Dimensions—T.)

(5) d—the lattice constant of the metal of which the film is formed. (Dimensions—L_*.)

(6) R—the distance between the anode and the cathode. (Dimensions—L_*.)

(7) u—the initial velocity of projection of the particles from the anode. (Dimensions—L_*. T^{-1}.)

The constant C has the dimensions L^{-1} as is clear from relation (10), hence it can be related to the various factors by the theory of dimensions and we get ultimately,

$$C = f.\ N.\ \frac{e}{m} F.\ t.\ d.\ R.\ \frac{1}{u^2} \quad \ldots \quad \ldots \quad (13)$$

where f is the function of distribution of the particles and has no dimensions.

If we adjust the conditions of the experiment in such a way that only one factor is variable while the others are kept constant, and the value of C be found out under those conditions, the above relation enables us to study the variation of N with the factor under consideration. In this way we can investigate all the factors one by one and thus obtain information about the phenomenon of anode-sputtering.

In the case of the copper and the platinum films that we have considered here, F is the same in both the cases, for the voltage on the tube was the same; t the time for which the tube was run was also the same in both the cases, *i.e.* 60 hours. Assuming that f is the same for all kinds of particles and u also to be of the same order in both the cases, we can write,

$$\frac{C_{cu}}{C_{pt}} = \frac{N_{cu}}{N_{pt}} \cdot \frac{m_{pt}}{m_{cu}} \cdot \frac{d_{cu}}{d_{pt}} \cdot \frac{R_{cu}}{R_{pt}}$$

or
$$\frac{N_{cu}}{N_{pt}} = \frac{C_{cu}}{C_{pt}} \cdot \frac{m_{cu}}{m_{pt}} \cdot \frac{d_{pt}}{d_{cu}} \cdot \frac{R_{pt}}{R_{cu}} \quad \ldots \quad \ldots \quad (14)$$

TABLE 4.

	mean k	$C = \frac{k}{R^2}$	d	m	R
Cu^+	·01069	$\frac{\cdot01069}{7\cdot6\times7\cdot6}$	3·63	63·57	7·6
Pt^+	·00255	$\frac{\cdot00255}{6\cdot8\times6\cdot8}$	4·03	195·20	6·8

$$\therefore \quad \frac{N_{cu}}{N_{pt}} = \frac{\cdot01069}{7\cdot6\times7\cdot6} \cdot \frac{6\cdot8\times6\cdot8}{\cdot00255} \cdot \frac{63\cdot57}{195\cdot2} \cdot \frac{4\cdot03}{3\cdot63} \cdot \frac{6\cdot8}{7\cdot6} = 1\cdot08$$

This shows that the number of particles sputtered out of copper or platinum anode is very nearly the same. It is remarkable that the same result is obtained in the case of the cathode-sputtering also where copper and platinum are contiguous in the list of metals arranged according to their sputtering value and both have very nearly the same sputtering value.[6]

It is clear that much reliance cannot be placed on the result obtained just above, for there are several factors involved at the same time in the experiment and also the value of C_{r_u} was obtained from insufficient data ; but the above deduction indicates the method by which the phenomenon of anode-sputtering may be profitably investigated.

A short remark on the possible source of the anode-sputtering may be made here. The analogous phenomenon of cathode-sputtering has evoked a lot of theories from a very long time. The current ones are—

(1) The vaporisation theory proposed by Hippel[7] and Waran[8] and supported by the experimental work of Cowsik.[9]

(2) The mechanical theory first proposed by Stark[10] which has led on one hand to the explosion theory of Bush and Smith[11] and on the other hand to the purely mechanical theory of Ingersoll and Sordahl.[12]

It appears that the vaporisation theory which has received quantitative confirmation in the case of cathode-sputtering and is quite plausible there, cannot be however applied in the case of anode-sputtering ; for it will necessitate the assumption of a certain point on the anode to be heated to a very high temperature due to the impacts of the electrons, whereas we find that the anode is sufficiently cool even after a very long discharge at high voltage.

The purely mechanical theory of Ingersoll and Sordahl according to which the sputtered particles are particles knocked out of the solid due to the back impact of the impinging particle, is also untenable here ; for it is highly improbable for an electron to knock out a particle in its recoil journey, there being very little energy in the electron for this purpose.

The explosion theory of Bush and Smith might however be applied in this case. According to this theory the electrons might be considered to produce a high pressure in the interior of the solid anode resulting in an explosion of the particles from the anode in all directions.

Another theory might be put forth that the particles are formed during the process of production or emission of X-rays from the anti-cathode. It is however no use going into mere speculations when there are no data to test the theories.

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PHYSICS LABORATORY,
SCIENCE COLLEGE, PATNA.

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